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THE RELATIONSHIP BETWEEN GLOBAL WARMING AND THE VARIATION IN TROPICAL CYCLONE FREQUENCY OVER THE WESTERN NORTH PACIFIC

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Abstract: The relationship between global warming and the variation in tropical cyclone (TC) genesis frequency is analyzed using the data of the ***Tropical Cyclone Year Book*** by the China Meteorological Administration and the National Centers for Environmental Prediction (NCEP) reanalysis data from 1949 to 2007. The observational results indicate that the average sea surface temperature (SST) in the Intertropical Convergence Zone (ITCZ) region (10°N – 20°N, 100°E – 140°E) increases by 0.6°C against the background of global warming, while the frequency of tropical cyclone geneses in this region decreases significantly. Generally, the rise of SSTs is favorable for the genesis of tropical cyclones, but it is now shown to be contrary to the normal effect. Most of the tropical cyclones in the western North Pacific (WNP) are generated in the ITCZ. This is quite different from the case in the Atlantic basin in which the tropical cyclones are mostly generated from the easterly wave. Our research results demonstrate that the ITCZ has a weakening trend in strength, and it has moved much more equatorward in the past 40 years; both are disadvantageous to the formation of tropical cyclones. Furthermore, our study also found that the ridge of the subtropical high tends to shift slightly equatorward, which is another adverse mechanism for the formation of tropical cyclones.

Key words: climatology, tropical cyclone frequency; long-term variation, ITCZ

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1 INTRODUCTION

It is assumed that higher SSTs are favorable for the greater cyclogenesis of tropical cyclones. Observational studies (e.g., Gray [1]; Chen et al.[2]; Ding[3]) have shown that 80% of the tropical cyclones (TCs) in the western North Pacific (WNP) occur in the Intertropical Convergence Zone (ITCZ) or monsoon troughs. For instance, Harr and Elsberry [4] pointed out that an active monsoon trough is correlated with enhanced TC activity. Wang et al.[5] showed that the summer monsoon system in the WNP causes cyclogenesis owing mainly to the intensification of the monsoon trough. Both studies also showed that warmer SSTs are advantageous to stronger initial disturbances over the ocean and, in turn, to more occurrences of TCs.

Recent studies, however, suggested that with global warming, there have been no increasing trends in TC frequency in response to greenhouse gases-induced ocean warming, as proven by a large number of evidences.

On the other hand, projections by individual climate models relating TC occurrences to anthropogenic forcing were heterogeneous. Some models unanimously showed global decreases in the frequency of TC formation (e.g., Sugi et al.[6]; Camargo et al.[7]; Bengtsson et al.[8]; Ouchi et al.[9]), with the simulated reduction of global TC frequency being positively correlated with the weakening of tropical circulation. Meanwhile, other modeling studies showed that TCs tend to increase (e.g., McDonald et al.[10]).

With respect to studies on observational TC activity, there are some concerns regarding the

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reliability of historical TC datasets, and their conclusions on the trends of climatic variation seem controversial. For instance, Webster et al.[11] examined the number of tropical cyclones and cyclone days, as well as tropical cyclone intensity, from 1970 to 2004. A large increase is seen in this 35-year period in the number and proportion of hurricanes reaching Categories 4 and 5 over global oceans, while the numbers of cyclones and cyclone days have decreased in all basins in the past decade, except for the North Atlantic. Some observational reanalyses were based on the hurricane database (HURDAT) for the Atlantic basin (Landsea et al.[12, 13]), and these studies showed that the annual number of TCs has exhibited multi-decadal variabilities. Meanwhile, other studies attempted to correct TC datasets by taking into account the TCs previously missing in the dataset for the North Atlantic basin (Vecchi et al.[14]). These studies showed that TC frequencies vary over the historical record, with increasing periods alternating with decreasing ones in the recent 125 years. Mann et al.[15] examined historical TC datasets that date to as far back as the late 19th century and found that TC counts are increasing with warmer SSTs in the Atlantic basin.

Recently, there have been several studies on the climatology of TC frequency in WNP, but there has been none on the reanalysis of TC historical datasets or the correction or addition of TCs possibly missing in earlier times. Chan et al.[16] showed a "trend" of interdecadal variation in the annual TC frequency in the WNP basin as they studied the best track data from the Joint Typhoon Warning Center (JTWC dataset hereafter) from 1960 to 2003. Extending the datasets to the 1960s, Chan [17] also suggested an interdecadal variation in the occurrence of category 4 and 5 typhoons over the WNP basin on the basis of the work of Webster et al. [11]. The study showed that the TC annual frequency has decreased over WNP since 1998 (Kimberlain et al. [18]).

During the past decades, it has been proven that Pacific warming is related to global warming, for which the fourth report of the Intergovernmental Panel of Climate Change (IPCC) provided the observational evidences (IPCC [19]). If this is the case, then how do ITCZ strength and geographical position change over the WNP responding to ocean warming and affect the frequency of tropical cyclone genesis?

2 DATA AND METHODS

Three datasets are compared for the observational TC frequencies over the WNP area from 1949 to 2007: the JTWC dataset [20], the best track data from the Tokyo-Typhoon Center of Japanese Meteorological Agency [21] (referred to as the JMA dataset hereafter), and the *Tropical Cyclone Year Book* [22] (referred to as the CMA dataset hereafter). The JMA dataset does not include information on tropical depressions (TD) and its wind records start from 1977 only. No TD data are included in the JTWC dataset before 1961, and no wind records of TCs below the intensity of a tropical storm were contained in the dataset from 1961 to 1970; wind records were not available for TCs until 1971 and TDs began to appear in the dataset of total frequency in the JTWC dataset from 2004. Of the three datasets, only the CMA dataset is the most complete and has the longest temporal span with regard to the record of total TC occurrence frequency over time from 1949 up to 2007.

Based on NCEP/NCAR reanalysis data with 2.5° lat. ×2.5° long. for horizontal winds and 2.0°×2.0° grid data for SSTs, a diagnostic analysis is performed in this paper to examine ITCZ strength and its position variation, as well as the SST distribution and variation in the area mentioned above.

Usually, on the seasonal and monthly time scales, the ITCZ is viewed as a nearly steady zonal band near the equator (Chen et al.[23]). In this study, July-October (JASO) is chosen as the seasonal mean based on two reasons. Firstly, the ITCZ strength during this period is stronger than other seasons, and its location is further northward. Secondly, JASO is chosen for our study because TCs are more frequently generated over this period than in other time periods.

3 OBSERVATIONAL FACTS

3.1 *Sea surface warming*

The worldwide sea surface has been continuously warming owing to the effects of global warming. The evidence shows the distribution of the averaged SSTs every 20 years (Figs.1a-1c) and the averaged differences in SSTs between the last 30, 20, 10 years and the first 30, 20, 10 years, respectively (Figs.1d-1f), in the WNP and the central Pacific in JASO from 1949 to 2008. It shows that the SSTs over the WNP have been gradually increasing during the past 60 years (Fig.1), in which the areas enclosed by the isotherm of 29°C expand eastward and northward with a maximum increment of 1°C around the central equatorial Pacific for the last 10 years (Fig.1f). This suggests that the warm pool, which is defined to be enclosed by a critical temperature of 28°C, has expanded eastward and northward in recent years (Ho et al.[24]). It shows that the SST time series in the ITCZ region (10°N – 25°N, 107°E – 140°E) has been rising in the past decades (see Fig.2) and there has been remarkable warming in the last decade, more than 0.8°C in some local areas (see Fig.1f).

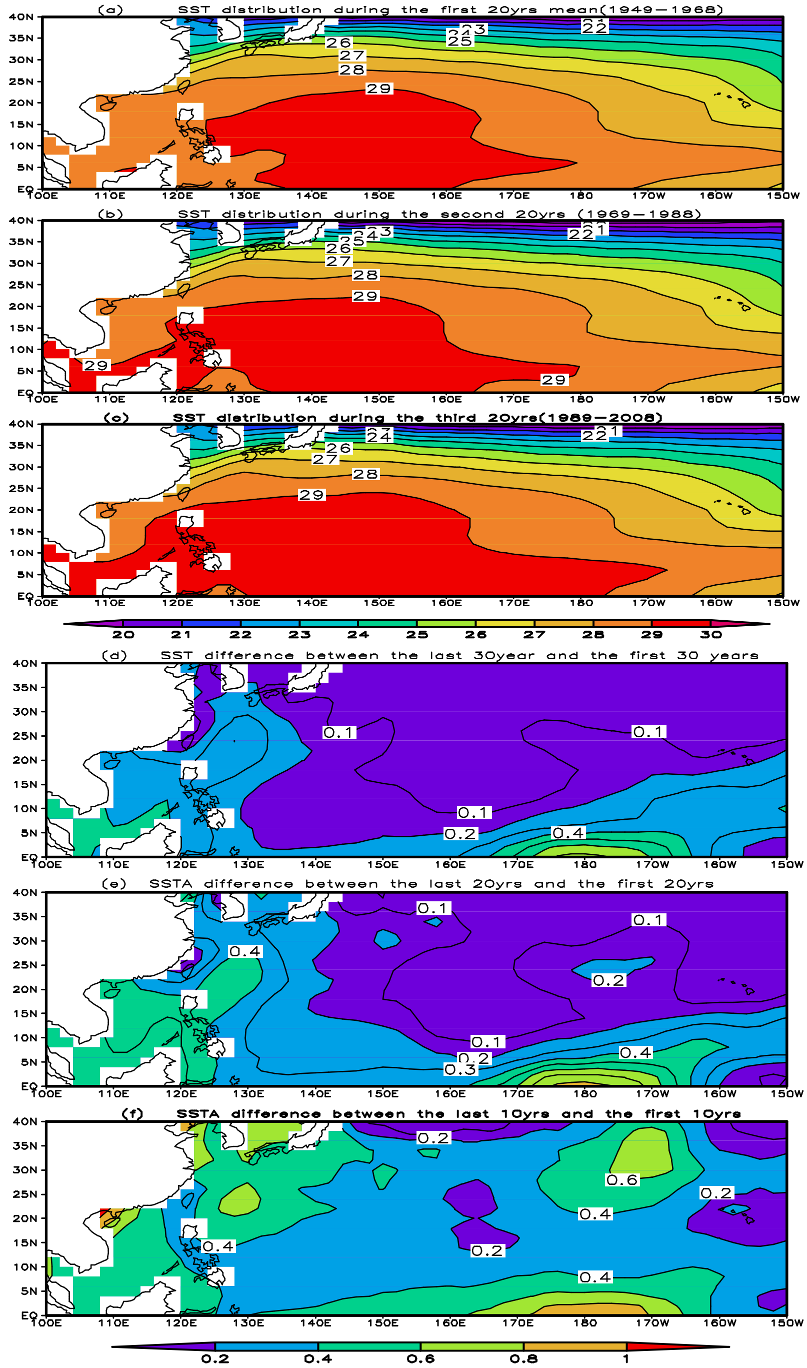

Fig.1 Sea Surface Temperature (SST) (in °C) distribution and its difference in western North Pacific. (a)-(c) SST fields averaged every 20 years over the WNP and central Pacific during the period from 1949 to 2008; (d)-(f) SST differences (in °C) between the last 30, 20, 10 years and the first 30, 20 and 10 years, respectively.

3.2 *Analysis of observational TC frequency*

Changes in TC frequencies (without the data of TDs) are analyzed with the three datasets introduced in section 2. It can be seen that the TC frequencies without TDs have interdecadal fluctuations with decreasing trends. Moreover, the three datasets are basically coincident with one another (Fig.3a). On the other hand, the analysis of the annual sum of TCs is based on the CMA dataset because it has the longest time span. The long-term frequency variations of typhoons (TY), severe tropical storms (STS), tropical storms (TS) as well as TD are determined based on the CMA data. The results show that in terms of frequencies, TY and TD have been decreasing remarkably from the start of the 1970s, STS has been decreasing slightly, while TS has been increasing slightly (Fig.3b). It is obvious that the total TC number has been decreasing in the past 40 years (Fig.3c) over the WNP.

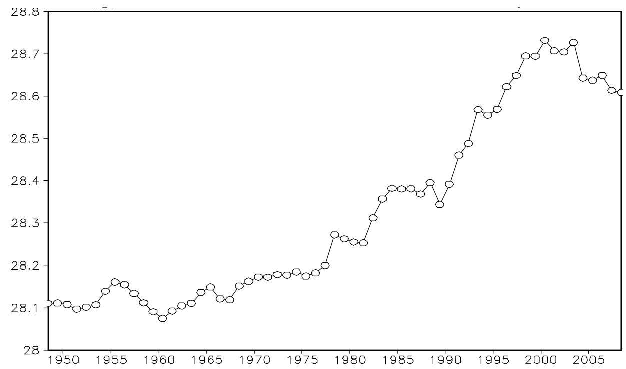

Fig.2 SST time series over (5-25°N, 110-140°E) area in JASO season during 1949-2008 (Y coordinate is for SST in ℃).

3.3 *TC formation conditions*

From the observational TC frequencies and SST distributions and variations in this study, we can see that warmer SSTs do not cause more TCs to form. Tropical cyclogenesis is related to several major favorable dynamical and thermodynamical conditions, such as higher SSTs, stronger low-level disturbance in the ITCZ, weak vertical wind shear, higher latitudinal position of ITCZ and the subtropical anticyclone ridge, and so on. Aside from these, Sugi et al.[6], McDonald et al.[10], and Chauvin et al.[25] suggested that dynamic factors such as low-level vorticity and vertical wind shear play a more important role than thermodynamical factors such as SST and moist instability. In this paper, we will try to study and understand why SST warming does not lead to an increase in TC frequency, with the focus on climate change and some other physical conditions crucial to TC formation.

4 RELATIONSHIP BETWEEN TC FREQUENCY AND ITCZ STRENGTH

4.1 *TC frequency and ITCZ patterns*

For our case study, we choose 5 highest frequency years of 1961, 1966, 1967, 1970, and 1971, and 5 lowest frequency years of 1995, 1998, 2003, 2005, and 2007; 1967 and 1998 are the most active year and inactive year, respectively (Fig.4). In fact, the highest frequency years appeared before 1970s, while the inactive years appeared in the late 1990s and at the beginning of the 21st century. It is known from the frequency of historical annual TC formation in the WNP and the diagnostic results based on the NCEP reanalysis data that, when tropical cyclones occur with higher frequency, the corresponding ITCZ is stronger, with the relative vorticity center reaching $1.2\times10^{-5}s^{-1}$ or beyond. In contrast, when the TC frequency is lower, the ITCZ is weaker, with the relative vorticity center reaching $0.6\times10^{-5}s^{-1}$ only and the whole zonal ITCZ being broken near 130°E (Fig.4b). Both case study and

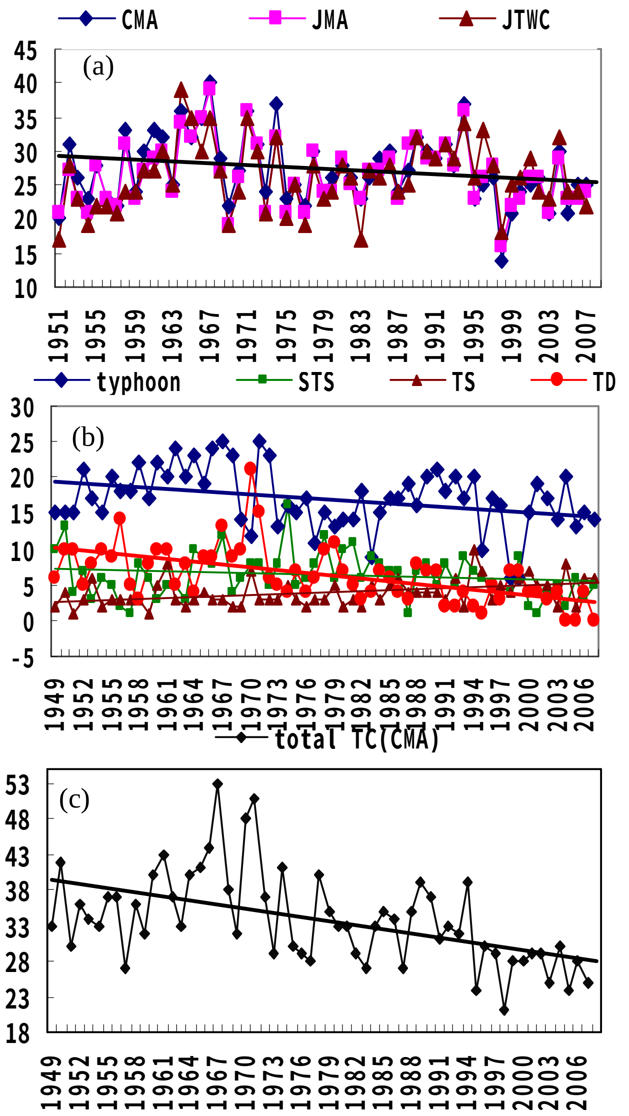

Fig.3 Tropical Cyclone frequency variation with time based on the CMA, JMA and JTWC datasets over the WNP (the coordinate is TC numbers. (a) Frequency variation for TCs without TDs from three datasets (bold line is trend in CMA dataset; (b) Frequency variations in TYs, STSs, TSs as well as TDs (the bold and fine lines are their trends respectively; (c) Frequency variations in total numbers of annual TCs, based on the CMA dataset (the bold line is the trend).

composite analysis obtain similar results on the relationships between TC frequency and ITCZ strength. It is shown that a strong ITCZ is accompanied by a strong southwest wind. It will strengthen the monsoon trough in the area west of 150°E.

4.2 *Variation in both TC frequency and ITCZ strength*

To examine the ITCZ (located at 10°N – 20°N, 100°E – 140°E) strength variability in the past 59 years, we applied a 10-year running mean to the annual TC data and JASO mean data from NCEP. It is noted

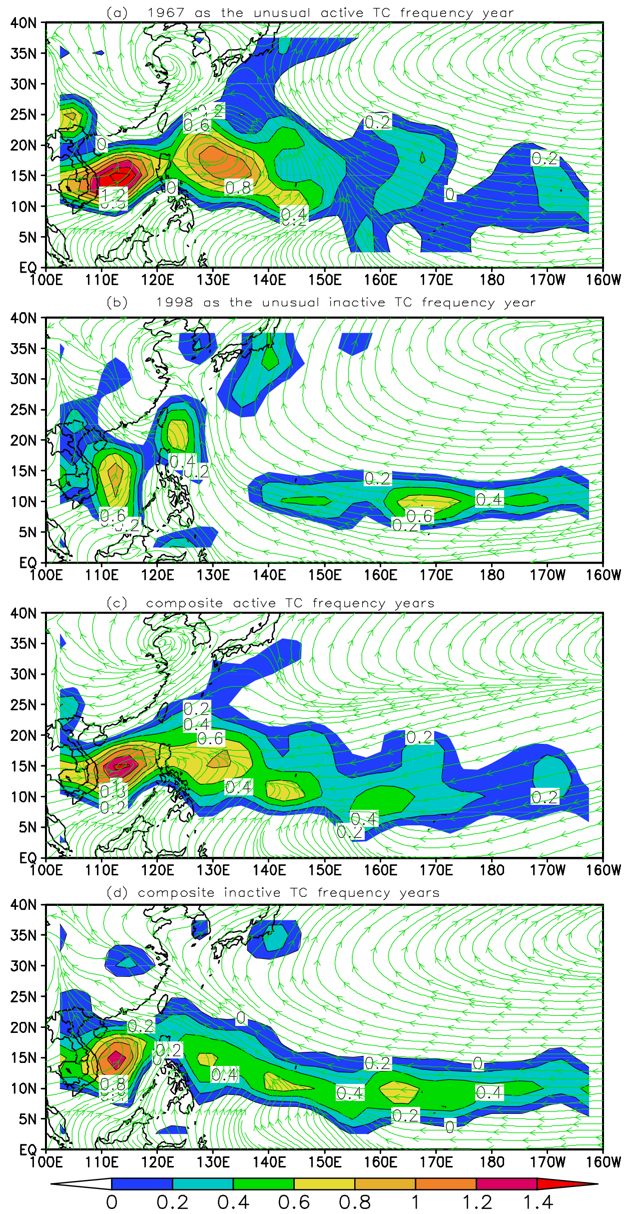

Fig.4 Stream fields-superimposed positive relative voticity at 925 hPa (the isoline values are positive relative vorticity in 10^{-5}) during JASO over the WNP. (a) Case for 1967 with frequency being the highest; (b) Case for 1998 with TC frequency being the lowest; (c) Composite case for active TC years; (d) Composite case for inactive TC years.

that the TC frequency trends over both the area west of 140°E and the WNP basin are positively correlated to the variability of ITCZ strength. It is indicated that the decrease of TC frequency is much positively correlated to the weakening of ITCZ strength (Fig.5a). In this study, the results show that the TC frequency variation has a similar trend with the ITCZ strength variation.

4.3 *Variation in ITCZ position*

Generally, the great strength and northward position of the ITCZ are favorable for TC formation; the opposite circumstances, however, are not favorable. In this study, we determine the central position of the ITCZ by singling out the points with maximum positive relative vorticity values for each 2.5 longitudinal distance within the 100°E – 140°E area and then averaging them. It is found that in JASO, the mean ITCZ position has a southward shift during the period from 1949 to 2007 (Fig.5b). The ITCZ position gradually moves equatorward during this period and reaches the lowest position around 10°N in 2003 and 2004 (the average position is 15°N), with the TC numbers at 30 over the WNP basin and 15 in the area west of 140°E, in 2003. In 2004, they are 24 and 13, respectively. The statistical data are all much less than those for the 1950s and 1960s when the TC frequency was much higher. From the long-term variation, it is seen that both the TC frequency trends over the area west of 140°E and the WNP are positively correlated with the variation in ITCZ position, that is, the reduction in TC frequency is much positively correlated to the equatorward shift in the ITCZ position (Fig. 5b).

4.4 *Variation in subtropical high position over WNP*

It is well known that TCs always occur in the area south of the subtropical high. Tropical cyclones do not form in very low latitudes mostly because of the weak Coriolis parameter. Consequently, the poleward shift of the subtropical high ridge is more advantageous to TC genesis and vice verse.

The research results in this paper also demonstrate that the average position of the subtropical high ridge based on the climate monitoring datasets [26] is shifting gradually equatorward (Fig.6), coinciding with the shift of ITCZ (Fig.5b). Both equatorward shifts are disadvantageous to tropical cyclone formation.

5 SUMMARIES

In the past 40 years, the sea surface has been warming rapidly and the mean SSTs have increased about 0.6°C in the WNP (west of 140°E). However, the frequency of TC against the background of global warming has decreased with time. The results of this research show that the following aspects may suppress the formation and frequency of TCs: (1) The vorticity within the ITCZ, located at (10°N – 20°N, 100°E – 140°E), is weakening in this period. (2) Shifting gradually equatorward. Both the ITCZ and subtropical high ridge are disadvantageous to the formation and development of TCs against the background of warming sea surface temperatures.

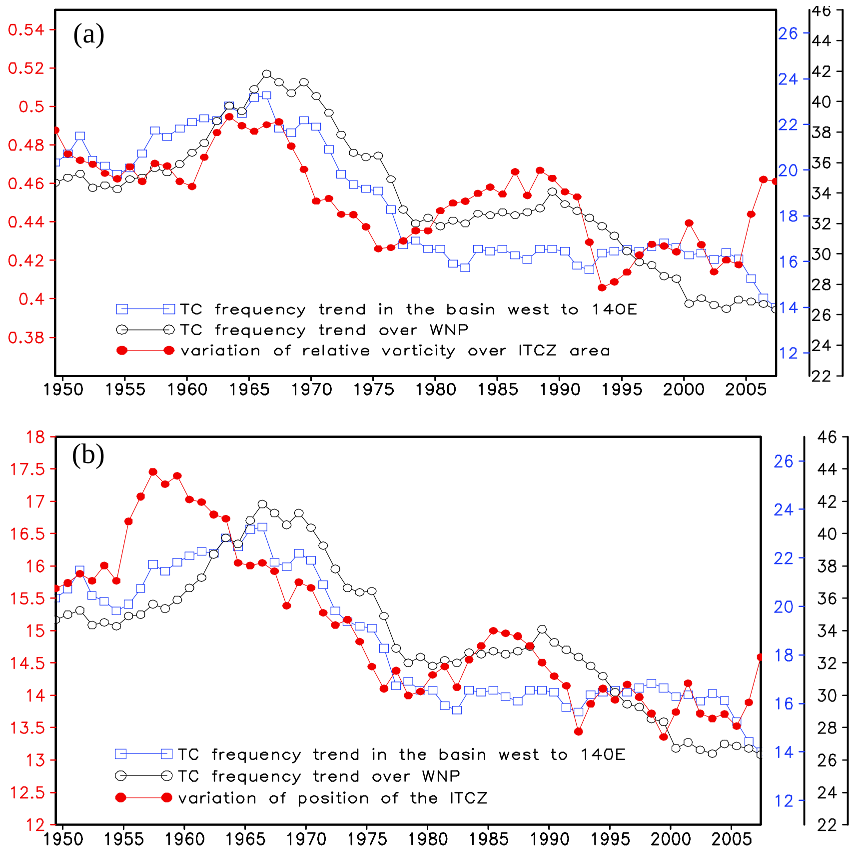

Fig.5 Long term trends in the TC frequency and variation of ITCZ strength and its position during JASO in 1949 – 2007. (a) Relative vorticity time series for the ITCZ area and annual TC frequency over the WNP and the basin west of 140°E (the left Y coordinate is for relative vorticity over the ITCZ, here in 10^{-5}. The first right Y coordinate is for TC numbers over WNP, the second right Y coordinate is for TC numbers in the basin west of 140°E; (b) variation of ITCZ position and TC frequency trends (the left Y coordinate is for the variation of ITCZ position (in latitude). The first right Y coordinate is for TC numbers over WNP and the second right Y coordinate is for TC numbers in the basin west of 140°E.) Note: Here a 10-y running mean is used for TC frequencies and ITCZ strength and position with high frequency fluctuations filtered off.

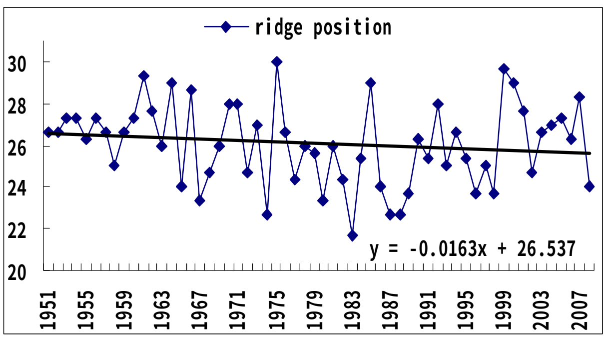

Fig.6 Variations of subtropical high ridge over WNP in June-September during 1951-2007.

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